Forest Policy and Economics 90 (2018) 22–30

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Adapting forest management to climate change in Europe: Linking perceptions to adaptive responses

Rita Sousa-Silva[a,*], Bruno Verbist[a], Ângela Lomba[b], Peter Valent[c], Monika Suškevičs[d], Olivier Picard[e], Marjanke A. Hoogstra-Klein[f], Vasile-Cosmin Cosofret[g], Laura Bouriaud[g], Quentin Ponette[h], Kris Verheyen[i], Bart Muys[a,j,*]

[a] Division of Forest, Nature and Landscape, Department of Earth and Environmental Sciences, KU Leuven, Celestijnenlaan 200E, Box 2411, 3001 Leuven, Belgium
[b] CIBIO/Inbio, Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade do Porto, Campus Agrário de Vairão, R. Padre Armando Quintas, n° 7, 4485-661 Vairão, Portugal
[c] Department of Forest Management and Geodesy, Faculty of Forestry, Technical University in Zvolen, 960-53 Zvolen, Slovakia
[d] Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Kreutzwaldi 5, Tartu 51014, Estonia
[e] Centre National de la Propriété Forestière, 47 rue de Chaillot, 75116 Paris, France
[f] Forest and Nature Conservation Policy Group, Wageningen University & Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[g] University Stefan cel Mare Suceava, Romania, Universitatii str. 13, Suceava 720229, Romania
[h] Earth and Life Institute, Environmental Sciences, Université catholique de Louvain, Croix du Sud 2, Box L7.05.09, 1348 Louvain-la-Neuve, Belgium
[i] Forest & Nature Lab, Ghent University, Geraardsbergsesteenweg 267, Gontrode, 9090 Melle, Belgium
[j] European Forest Institute (EFIMED), Sant Pau Historical Site, Sant Leopold Pavilion, carrer Sant Antoni Maria Claret 167, 08025 Barcelona, Spain

ARTICLE INFO

Keywords:
Adaptive capacity
Awareness
Climate change
Europe
Forest management
Regional differences

ABSTRACT

Climate change will impact forests and may impair their ability to provide essential ecosystem services in the decades to come. Addressing this challenge requires adjustments to forest management strategies as of now, but it is still unclear to what extent this is already in progress. Using data from surveys of 1131 forest owners and managers from seven European countries, we assessed how they perceive their role in adapting forest management to climate change. The surveys focused on foresters' observations of climate change impacts, the degree to which climate change is a part of their operational and strategic management, and their ability to address related risks and opportunities.

We found evidence of a strong continent-wide climate change awareness among respondents, with 73% foresters convinced that climate change will impact their forest. However, only about one-third (36%) reported having modified their management practices, though figures vary widely between countries, from 14% in Portugal to 57% in Slovakia. Among the constraints limiting their actions, lack of knowledge and information emerged as a major barrier towards forest adaptation. Differences between countries could be linked to their socio-economic and political contexts. Our results further suggest that severely damaging events, such as windstorms, fires and pest outbreaks, present relevant opportunities to engage people with climate change and encourage action. Further work needs to be done in strengthening the relationship between scientific research and practice, working out context dependent measures to foster adaptation to changing climate and disturbance regimes in forest management.

1. Introduction

Forests are of utmost importance for the environment, the economy and the society, as they provide multiple goods and services (Crowther et al., 2015). Climate change, in particular increased temperatures, changes in precipitation patterns, and extreme weather events, will inevitably have widespread impacts on forests and forestry. Among the known impacts of climate change are changes in tree growth and productivity (Bergh et al., 2003; Jump et al., 2006), changes in tree health and species composition (Allen et al., 2010; Kurz et al., 2008), and damages caused by natural disturbances (Dale et al., 2001; Seidl et al., 2014).

Minimizing the risks and impacts of climate change on forest management outcomes and reducing the vulnerability of forests to

* Corresponding authors. Division of Forest, Nature and Landscape, Department of Earth and Environmental Sciences, KU Leuven, Celestijnenlaan 200E, Box 2411, 3001 Leuven, Belgium.
E-mail addresses: anarita.silva@kuleuven.be (R. Sousa-Silva), bart.muys@kuleuven.be (B. Muys).

https://doi.org/10.1016/j.forpol.2018.01.004
Received 26 July 2017; Received in revised form 27 November 2017; Accepted 17 January 2018
Available online 04 February 2018
1389-9341/ © 2018 Elsevier B.V. All rights reserved.

climate change requires adaptation (Nelson et al., 2016). However, despite the recent research efforts, integration of adaptive forest management measures, taking into account expected climatic change, is a challenge yet to tackle. Unlike other sectors, such as agriculture, adaptation measures for forestry need to account for the long time lags between the establishment and maturity of trees. Forests regenerated today will have to cope with the future climate conditions of at least several decades, often even more than 100 years (Lindner et al., 2008; Wagner et al., 2014).

IPCC defines adaptation as an 'adjustment in natural or human systems in response to actual or expected climatic changes or their effects, which can be taken to reduce the impact of a particular risk or exploit its beneficial opportunities' (IPCC, 2014). Adaptation can be classified either as autonomous or planned (Schoene and Bernier, 2012). Autonomous adaptations are usually reactive, drawing on existing knowledge and technology to respond to changing climate conditions. Planned adaptations are anticipatory responses, often multilevel in nature, aimed at altering the adaptive capacity of the forestry system or facilitating specific adaptations. Messier et al. (2015) argue that changing conditions must be anticipated rather than simply recognized as they occur, since a reactive approach may be ineffective when dealing with long-lived organisms such as trees. Planned adaptation thus entails the involvement of the entire community of forest practitioners, from the field managers to the policy makers, to ensure that future forests are better aligned with the needs and preferences of local people (Kolström et al., 2011). Advantages of such involvement include a broader base of policy support and enhanced sharing of information and expertise on how to address climate adaptation needs (Fernandez-Gimenez et al., 2008; Messier et al., 2015).

A multitude of strategies to adapt forest management to climate change have been proposed (e.g., Bolte et al., 2009; Kolström et al., 2011). Some of these measures are not new and have already been used in forest management long before climate change became an issue. One example is the 'back-to-nature' approach, which promotes species mixtures and irregular age structures as a response to even-aged plantations (O'Hara, 2016). However, despite its apparent reliance on ecological arguments, the underlying rationale for reintroducing more complex forest stand structures was economic and most 'back-to-nature approaches' are still production-oriented (Gamborg and Larsen, 2003). Another example is the systemic silviculture approach. It does not depend on targeted structures or composition, as is generally the case with back-to-nature silviculture, but tends to follow and adapt interventions to the natural response of each stand (Ciancio and Nocentini, 2011; Nocentini et al., 2017). Furthermore, forest management and policy decisions are based on interactions between actors that engage with and react to one another (Nocentini et al., 2017).

One thing that all these approaches have in common is that planning for climate adaptation requires a longer-term perspective that must be effectively communicated and perceived. Perception is recognized as an active process of understanding, through which individuals construct their own version of reality (Pickens, 2005) and therefore influences decisions. Increasingly, the importance of foresters' perception of climate change and options for adaptation is being recognized (Blennow et al., 2012; Lawrence and Marzano, 2013; Yousefpour and Hanewinkel, 2015; Sousa-Silva et al., 2016), since they play a fundamental role in the development and implementation of adaptation strategies, policies, and actions (Keenan, 2015).

Therefore, to further support the design and implementation of adaptation measures and policies in forest management, the purpose of this paper is to assess the level of adaptation of forest owners and managers, and the constraints that hinder or prevent adaptation. Although previous studies have shown that the capacity of forest owners to adapt to climate change is strongly dependent on the individual's strength of belief in climate change and in the adaptation measures (e.g., Blennow et al., 2012; Yousefpour and Hanewinkel, 2015), direct comparisons between countries based on studies already carried out are not feasible as the data are based on different questionnaires, methodologies and reference years. Here we seek to fill this gap by conducting a large-scale survey across Europe addressing three questions: (1) *to what extent are forestry practitioners aware of climate change*; (2) *what adaptation strategies do they practice to mitigate the impact of climate change, if any*; and (3) *what are the major factors which account for the success or failure of forest adaptation in each country*.

As such, this study provides a unique overview across countries of the perceptions of forest owners and managers, in order to develop the most appropriate recommendations for adaptive forest management under climate change.

2. Methods

This study is based on surveys carried out among forest owners and managers in seven European countries: Belgium, Estonia, France, the Netherlands, Portugal, Romania and Slovakia. Countries were chosen according to the following criteria: (1) to be representative of different biogeographical regions in Europe; (2) a large variation in extent of their forested area (as a percentage of total land area of the country); and (3) differences in socio-economic, political and cultural context. By including countries from Southwestern, Central and Eastern Europe, this assessment covers, therefore, different forests, climate conditions, and divergent governance-policies and strategies to support adaptation of forests to climate change (Appendix A).

The first survey was carried out between April 2013 and June 2014 in Romania and the second one between April 2015 and June 2016 in the other six surveyed countries. For detailed information on the survey design and sampling procedures see Appendix B. Questionnaires were formulated in English, on the basis of similar previous published surveys, and translated into the native languages of respondents in each respective country. Minor changes were made in the translation for a better adjustment to the targeted countries. A total of 1131 respondents completed the surveys, which included information on demographic factors, climate change awareness and self-reported adaptive measures taken. The main questions are shown in Table 1 (additional information is detailed in Appendix B). All respondents did not answer every question. The number of respondents to each question is reported for each table or chart.

The surveys were launched online and disseminated through email lists and social media targeting organizations active in the forest sector in the surveyed countries. Respondents were asked to forward the questionnaire to other colleagues and to any network in which they were involved to expand the snowball sample. Surveys were also

Table 1
Beliefs, experiences and ability of forest practitioners to contribute to climate change adaptation. *N* is number of responses.

General beliefs in climate change (*N* = 1131)
Do you think that climate change is happening?
Do you think that forest management must change in order to cope effectively with climate change?
To what extent are you concerned about climate change?
General experiences of climate change impacts (*N* = 1131)
Have you experienced any extreme weather event that you interpreted as caused by climate change?
If yes, which changes have you observed?
Beliefs of potential impacts (*N* = 1131)
Do you think that climate change will affect your forests?
If yes, which changes are you expecting?
Implementation of adaptation actions (*N* = 885)
Have you adapted your forest management in response to climate change?
If yes, what changes have you made to your management?
What are the greatest constraints limiting your ability to implement climate change adaptation actions?
What assistance would you require to address climate change in your forest?

distributed as paper copies during specific meetings in Belgium, Portugal, Romania and Slovakia. For analysis purposes, respondents were grouped into three categories based on their responses to questions about their status and organizational/institutional affiliation: forest owners, private managers, and public managers (Table B.2). Variation in the total number of respondents per stakeholder group and per country reflect different sampling efforts and the availability of contacted stakeholders to take part in the study.

Results from surveys were first assessed through exploratory analyses, after which differences in beliefs and experiences between forest owners and public and private managers were tested using the Kruskal-Wallis test. Afterwards, Spearman's correlation analysis was used to examine how individual beliefs and experiences were related to the intention of managers to adapt. Item scores are presented as mean ± SD (standard deviation). All statistical analysis were performed in R software (version 3.3.2).

3. Results

3.1. Perceptions of climate change: beliefs and experiences

Analysis of the respondents for differences between forest owners and public and private managers showed that owners were significantly older (Kruskal-Wallis test: $P < 0.001$). Regarding their level of education and years of management experience, there was no statistically significant difference between the three groups assessed. Management decisions of private forest owners are largely dependent on themselves, while forest managers choices result from a joint decision-making process (e.g., in consultation with forest associations).

The majority of respondents considered climate change as a fact (91%), with 74% referring that climatic changes are partly or mainly driven by human activities. Conversely, 6% of respondents across all targeted groups considered climate change to be an unlikely phenomenon or denying its existence. Furthermore, 56% reported previous experience of climate change-related events in their own forests, with windstorms, droughts, heatwaves, and extreme precipitations being the most frequently mentioned (Fig. 1a).

Overall, respondents referred to be 'somewhat concerned' about climate change (1.8 ± 1.2, where 0 = not at all concerned and 4 = extremely concerned), with the majority of respondents (73%) expecting to observe changes in forests as a result of climate change. In the future, respondents primarily expect an increase in the incidence of extreme weather events (70%) and pest outbreaks (60%). Seventeen percent expects forest growth declines (Fig. 1b). There was no observable difference between the three groups regarding whether they thought climate change would affect their forests (2.8 ± 1.2). Forest managers – both public (2.1 ± 1.2) and private (2.0 ± 1.2) – expressed slightly but not significantly higher concern about its impacts on forests than did forest owners (1.7 ± 1.2).

Forest owners, private managers, and public managers did not differ significantly in their beliefs and expectations, both with regard to climate change in general as well as concerning its current and potential future impacts ($P < 0.001$). A significant relationship between experiencing extreme weather events and expressions of concern about climate change was observed ($P < 0.001$); however, the strength of the relationship is weak ($r_s = 0.34$).

3.2. Perceptions on adaptation of forests and forest management

When asked whether the respondents believed in the need to adapt their management practices to cope with climate change, more than half (54%) of those surveyed shared that view (Fig. 2a). Interestingly, public managers were more likely to support adaptation actions (73%) than private managers (58%) or forest owners (48%). Despite this belief, 60% of respondents stated that they have not yet adapted their forest management practices in response to climate change (Fig. 2b). Managers of public forests were found to have the highest value of positive answers for having adapted their management (52%). Questions about having taken measures to adapt were not directly asked in the Romanian survey (hence $N = 885$).

Belief regarding the need to adjust forest management practices had a significant influence on intended adaptive response of respondents towards changing their management practices ($P < 0.001$). However, the relationship between the general belief in climate change and the intention to adapt forest management, though significant, was low ($r_s = 0.24$, $P < 0.0001$). Likewise, the perceived experience of climate-induced changes and the expectation to see more of these changes in the future did not significantly alter an individual's intention to adapt to changes.

Among respondents who reported having made changes to their management (36%; $N = 885$), forest regeneration, including selection of tree species and varieties (92%), and strengthen diversification of tree species mixtures (69%) were among the most cited adaptation measures. When asked about the constraints faced when implementing climate change adaptation actions, lack of technical knowledge (30%) to implement these actions and lack of information (27%) stood out as being the most important (Fig. 3a).

As for the constraints to implement climate change measures, respondents were asked what assistance they would require to address climate change (Fig. 3b). A majority of respondents (49%; $N = 885$) indicated that policy and financial incentives would make them more likely to undertake adaptation actions, with demands for more

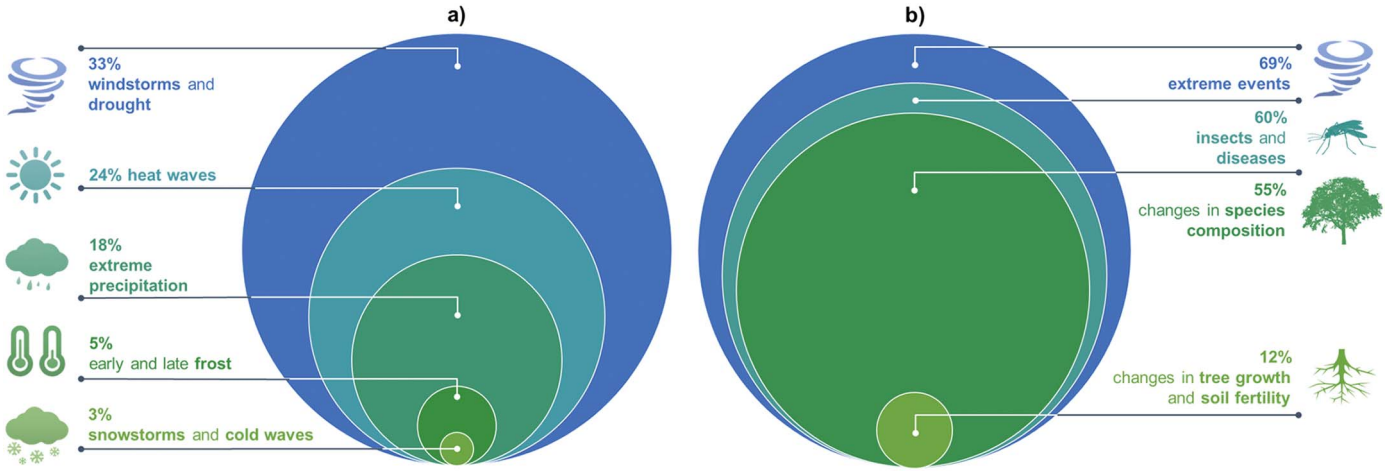

Fig. 1. Experienced extreme events perceived as climate change related (a), and expected future impacts on forests (b). Circle areas are proportional to the number of responses.

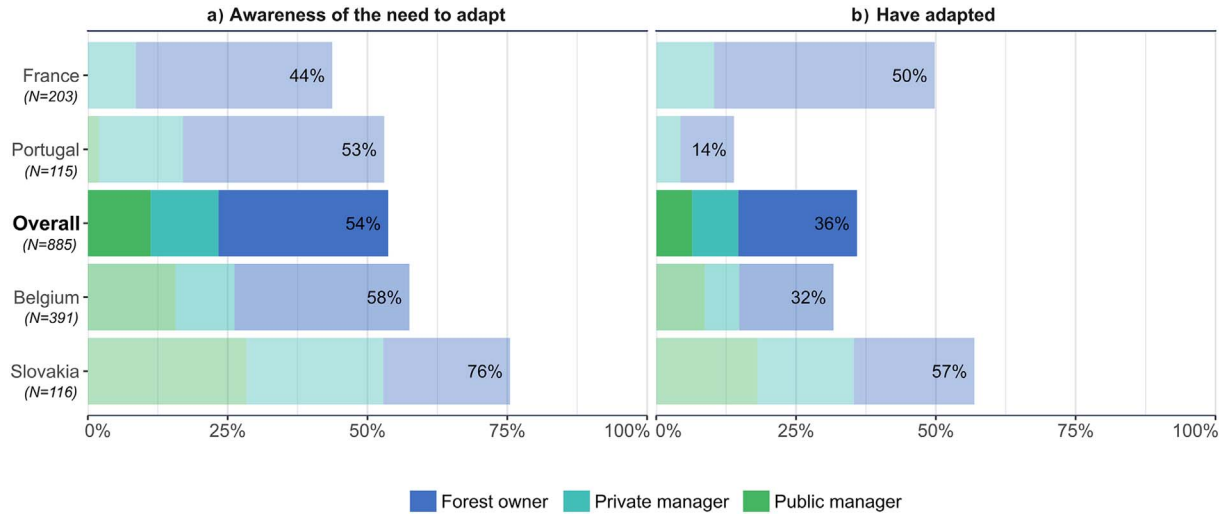

Fig. 2. Self-awareness of the need to make changes to forest management as a consequence of climate change (a), and of having taken measures to adapt (b). Samples are sorted according to the order along the left panel. Results are not shown when $N < 100$ (Estonia, $N = 40$; and the Netherlands, $N = 20$). The question about adaptation of management was not included in the Romanian questionnaire.

information (39%) and technical assistance (33%) coming third and fourth, respectively. When it comes to advice about climate change adaptation, private forest owners and managers say that they largely rely on forest associations (accounting for 61% and 59% of answers, respectively). Public managers identified policy guidelines and recommendations as their primary sources of information (52%), followed by participation in training courses (50%). Less than 15% of the respondents stated that they made use of the scientific literature. The expert opinion of forest managers (i.e. their peers) is also highly valued when planning management decisions (44%).

3.3. Key findings across targeted countries

When looking at countries individually, our survey reveals that the strength of belief in climate change is consistently high across all surveyed countries (Table 2). On the other hand, respondents' strength of belief in having experienced climate change differs markedly among countries (Fig. 4). Slovakian respondents most strongly believed that they had experienced climate change and that the climate is changing to such an extent that it will substantially affect their forest ($P < 0.001$; Table 2, details in Appendix C). Contrastingly, Estonian respondents less strongly believed that they had experienced climate change. Most notably, in Estonia, 14 out of 40 respondents expect climate change to have a positive impact on forest growth, while in other countries the proportion fell below 5% (e.g., in Portugal and Slovakia).

The largest fraction of respondents who stated they had taken measures to adapt the management of their forest to climate change were found in Slovakia (57%) and France (50%), with the smallest fraction observed in Portugal (14%). When asked about what they felt were the main constraints limiting climate change adaptation, lack of technical knowledge and information ranked high among the major constraints to all. For Portuguese respondents, however, the foremost constraint identified was lack of finances or financial incentives (57%).

Although Romanian respondents were not directly asked whether they had adapted their management practices, they were asked about their trust in measures to prevent negative effects of climate change. Interestingly, 55% of respondents think that the national forest policy is appropriate to prevent adverse effects, though its implementation can be improved (Appendix B).

4. Discussion

4.1. Climate change awareness – what do we know?

The challenge of adapting to climate change is now recognized to be

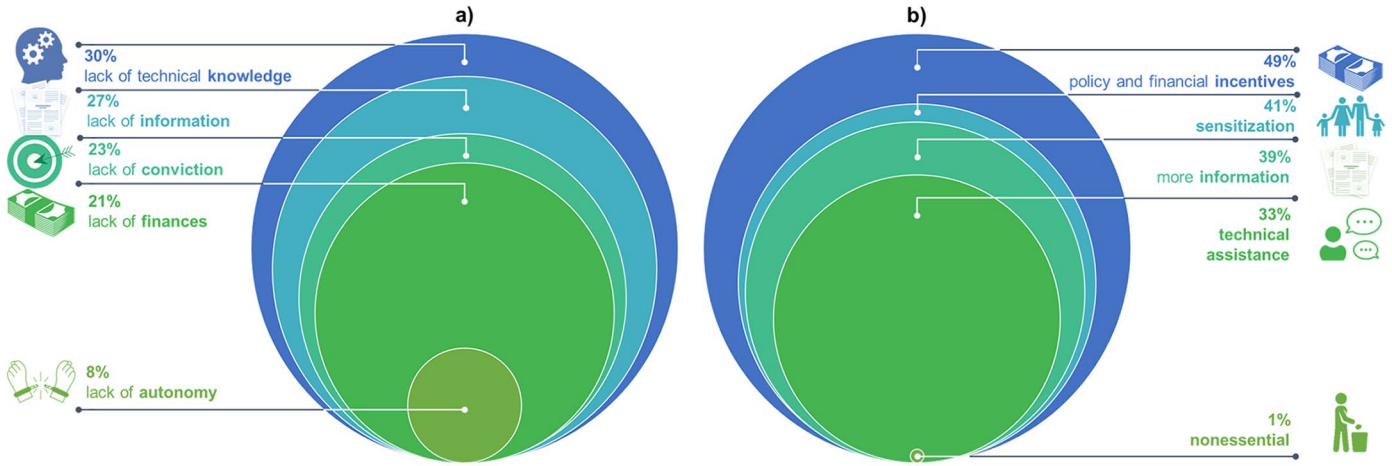

Fig. 3. Constraints limiting climate change adaptation (a) and assistance required to address those impediments (b). Circle areas are proportional to number of responses. Respondents from Romania did not answer question about adaptation of management.

Table 2
Differences in beliefs, experiences and ability of forest practitioners to contribute to climate change adaptation between countries. Respondents from Romania did not answer questions about adaptation of management. Significant differences tested with Kruskal-Wallis test ($P < 0.001$), and *post-hoc* with Dunn's test ($P < 0.05$; Appendix C).

	Belgium	Estonia	France	Netherlands	Portugal	Romania	Slovakia	*P* value
General beliefs	95%	75%	82%	75%	93%	91%	98%	< 0.001
General experiences	50%	35%	55%	55%	55%	61%	80%	< 0.001
Beliefs of potential impacts	71%	68%	64%	45%	82%	81%	83%	< 0.001
Implementation of adaptation actions	32%	15%	50%	25%	14%	–	57%	< 0.001
Number of responses	391	40	203	20	115	246	116	1131

one of the most important and difficult ever posed to the forest sector. Aside from the scientific consensus on climate change (Maibach et al., 2014), our findings about respondents' perceptions of climate change and the need to have adaptation measures converge with those of Blennow et al. (2012) and Yousefpour and Hanewinkel (2015): there is a high awareness about climate change issues among forest owners and forest managers. The results show that European foresters are convinced that climate is changing ($\bar{x}$ = 91%) and that it may induce further changes in their forests ($\bar{x}$ = 74%). Also noteworthy is that more than half of the foresters are already experiencing its impacts ($\bar{x}$ = 56%), though this differs per country, varying from 35% in Estonia to 80% in Slovakia.

While the evidence that climate is undergoing perceptible changes has become increasingly clear (EEA, 2017; IPCC, 2014), the question now is how to manage forests in the face of it. In line with previous studies that have shown that forest owners' strength of belief in climate change influenced adaptation (e.g., Blennow and Persson, 2009), the results presented here confirm these findings. Interestingly, our results go beyond such findings by showing that believing per se does not necessarily lead to further action on climate change (see also Grothmann and Patt, 2005). On the one hand, personal experience of climate change effects and willingness to take action on climate change may provide further key pieces of the adaptation puzzle (Spence et al., 2011; Reser et al., 2014; Demski et al., 2016). In our study, direct experiences of climate change showed a weak but significant positive association with the adaptive responses of forest owners and managers

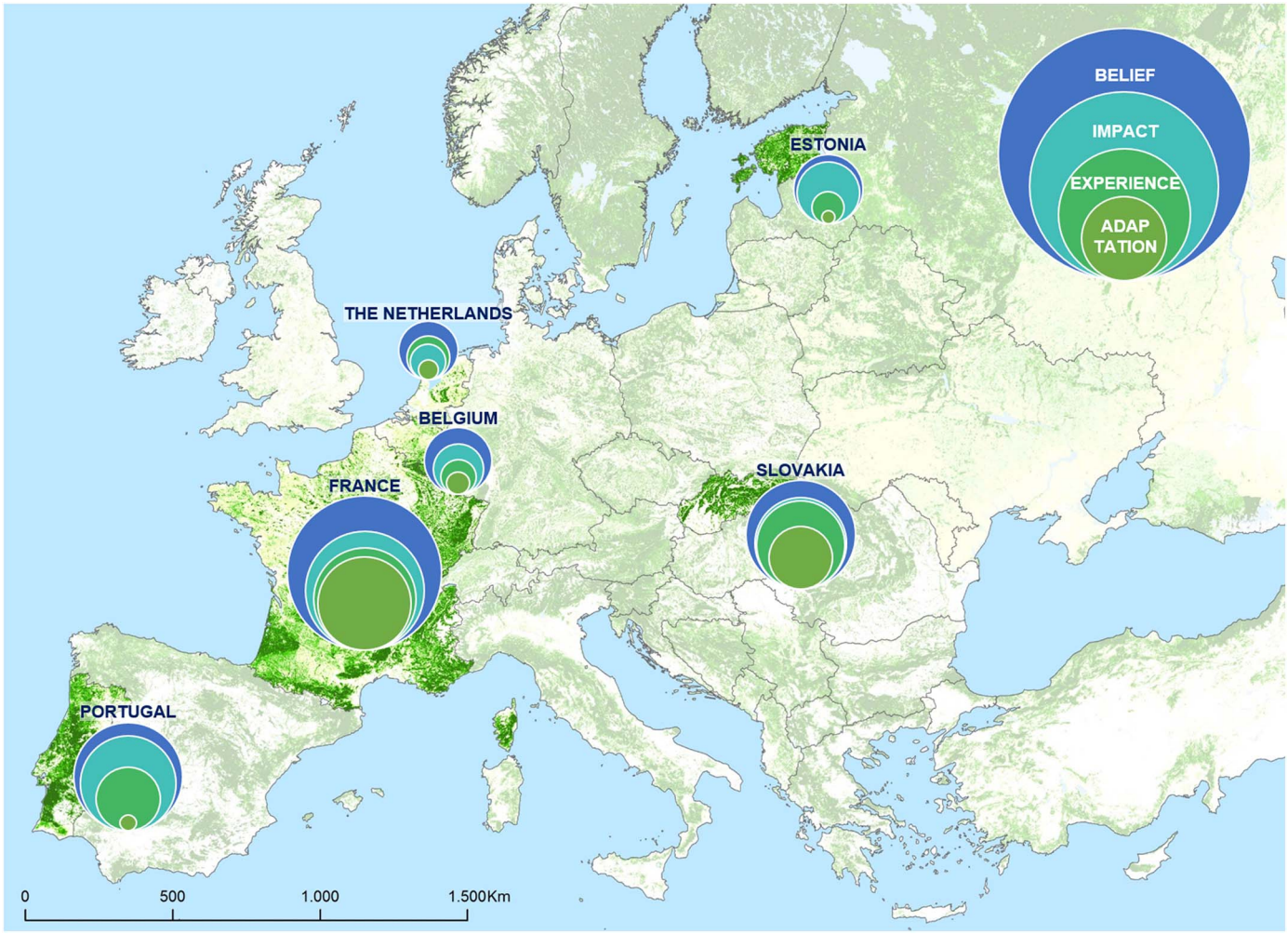

Fig. 4. Beliefs and perceptions about climate change: general belief (blue), awareness of potential impacts (tile), personal experiences (sea green), and implementation of climate adaptation actions (apple green). Data on adaptation to climate change were not available for Romania. Countries surveyed are at 100% opacity with the forest cover map of Europe in the background (Kempeneers et al., 2011). Venn diagrams are proportional to sample size for each country and circle areas are proportional to number of responses. Note: For graphical clarity, Venn diagram of Belgium is not to scale. An accurate representation of its scale is shown in the upper right corner. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(r_s = 0.3, $p \leq 0.001$). But on the other hand, the lack of information and the limited access to financial resources may hinder the implementation of adaptive measures. As shown here, approximately half (49%) of respondents who believed that climate is changing and that had experienced climate change referred that they have not yet adapted their forest management accordingly.

Additionally, it has also been argued that forest owners and managers must be aware of the implications of climate change in order to develop adaptation strategies that may help to reduce adverse effects and sustain productive forests (Yousefpour and Hanewinkel, 2015). The fact that 26% of the respondents feel that adaptation is not necessary at this point and that 13% of respondents are not at all concerned may suggest that a significant portion of forest management practitioners are not yet fully convinced that forest management should be changed to account for climate change. Perhaps more strikingly, Portuguese respondents, who expressed greater concern about climate change as compared to those in the other countries, were found to maintain the lowest level of change in forest management. In the other surveyed countries, the level of concern is relatively low (below 50%). These results, in line with other surveys on this matter (Lawrence and Marzano, 2013; Nelson et al., 2016), further stress the need to raise awareness and stimulate appropriate action on climate change among forest practitioners. Furthermore, of those who are engaged or interested in adaptation, almost 70% indicated that they have not yet taken action. This observation raises important questions regarding the development and implementation of climate change adaptation options in forest management (Bouriaud et al., 2015). A possible explanation for this may relate to the uncertainty about the many factors to be considered by the forest manager in their decision-making (de Bruin et al., 2015; Keenan, 2015; Millar et al., 2007). In a recent study of forest planners in Britain, Petr et al. (2014) described climate change uncertainty as a key reason for inertia to climate change adaptation in forestry. Nineteen percent of respondents share this opinion. However, incorporating uncertainty into management should be interpreted as an opportunity to use a wider variety of treatments and to carefully weigh responses to unplanned events and disturbances, including simply accepting them as an inherent and therefore valuable part of the possible and desirable conditions (Messier et al., 2016).

4.2. Adaptive forest management – what can be done?

There are three possible approaches for adapting forests to climate change: no intervention, reactive adaptation and planned adaptation (Bernier and Schoene, 2009). Unfortunately, most current management belongs to the first, or at best to the second category. Uncertainty, but above all else, insufficient information or information of poor quality, along with limited technical capacity, are the key aspects leading to a lack of adaptive responses. When asked about the main constraints limiting their ability to adapt to climate change, most of our respondents said they were poorly informed about climate change and possible adaptation options. Similar findings have been described, for example, in Germany (Yousefpour and Hanewinkel, 2015) or Sweden (André et al., 2015), as elsewhere (FAO, 2012). In this context, it is of relevance to note that fewer than one-quarter of respondents stated that they were not convinced that climate change actions are important, which is of less importance than the lack of technical knowledge or poor access to information. This evidence supports the idea that other factors, such as knowledge and capital, are more relevant in determining whether forest owners and managers have the capacity to make adjustments in forest management practices.

Adapting to climate change also includes exploring new opportunities that arise, for example from planting provenances or species that will grow faster under projected climatic conditions. In agreement, our results highlight that introducing tree species (or varieties) that are believed to be better adapted or adaptable to the changing climatic conditions is among the most supported options for adapting to climate change. Nonetheless, suggesting to favor better adapted species, without specifying which species may perform better under a changed climate, is not sufficient to ensure effective implementation of these actions. Indeed, several respondents pointed out that more information on the recommended species could assist them to manage their forests for climate change. However, as we are still lacking the knowledge of which species, provenances or genotypes will thrive in the future, there is a need to gain new knowledge on which to build future decisions (i.e. which trees turn out to be better fitted to the climate change or what silvicultural treatments should be applied to maintain the desired species throughout the entire stand rotation) (Coll et al., 2018; Fady et al., 2016). But even more important is that vulnerability assessments are almost completely lacking at national level (Lindner et al., 2008). Better understanding of regional differences in vulnerability and exposure to climate change is crucial for targeting planning adaptation measures (Kolström et al., 2011). For instance, a recent study among forest stakeholders in Norway showed that none of them expressed deep concern about climate impacts on forests (Heltorp et al., 2017). Instead, they regard climate change as an opportunity rather than a threat for the forest sector. This therefore suggests that, if adaptation is to be successful, those who report unconcern over climate change, for instance, as shown here for Estonia (20%), France (18%) and Slovakia (24%), must be motivated to engage in climate change adaptation as an incentive rather than an obstacle.

Finally, for adaptation to be successful it is of utmost importance to involve all stakeholders in the discussion and proposal of adaptation measures (Keenan, 2015). Broad stakeholder participation enables the development of shared values and goals, which strengthen the forest sector and facilitate public and private engagement. Managers must be given the flexibility to respond in ways that meet their particular needs and capacity to choose management options that are suitable to the local context. In this regard, different forest policy-making patterns in Europe may offer different perspectives for stakeholders participation in adaptation decisions, and different degrees of freedom of decision on adaptation measures to be implemented (Bouriaud et al., 2015). It must be emphasized that both impacts and adaptation measures vary considerably in the European regions, which makes it difficult to establish a conclusive approach throughout Europe, and further stresses the relevance of local expert knowledge. Local experts may provide additional (often overlooked) information on climate change impacts and fill knowledge gaps for less-described European regions (Spathelf et al., 2014).

4.3. What are the priorities for Europe's forest sector on climate change adaptation?

While progress has been made developing and synthesizing general climate change impacts and adaptation knowledge (see for example Millar et al., 2007; Seppälä, 2009; Lindner et al., 2010; Lindner et al., 2014; Keenan, 2015), the implementation of on the ground adaptation actions has not yet occurred to a substantial extent. Only relatively recently national adaptation strategies have begun to include measures by which forestry can adapt to climate change (Keskitalo, 2011). For example, in France, a national plan for adaptation to climate change was launched in 2011 (MEDDE, 2011). It proposed mainly adaptive capacity building measures, including for the forestry sector to intensify research and development efforts, collect and diffuse ecological data widely and ensure impact monitoring. However, all these plans and projects are based on networking with no additional funding (Keskitalo et al., 2015). This is but one example that, in order to implement the necessary adaptation measures, there is a need for the national governments to provide an appropriate institutional setting, with supporting policies and funding mechanisms, to make things work (Biesbroek et al., 2010). While it is true that most adaptation actions will occur at regional and local scales, national and international responsibility is also important.

In this respect, one should bear in mind that despite institutional differences in political priority, availability of resources, size and scales of research programs, institutions and organizations already in place and the external pressures of public and private organizations, international, national and regional cooperation can facilitate adaptation to climate change impacts through integrated planning and management (Biesbroek et al., 2010; Joyce et al., 2009; Keskitalo, 2011). Therefore, a common European framework for climate adaptation needs to account for socio-economic and social-ecological regional differences in order to maximize the effectiveness of action at multiple scales, thus ensuring a consistent level of adaptation across Europe. Indeed, the differences in national forest management systems across Europe are significant (Nichiforel et al., 2018). These differences, both among countries and between regions, may partly be explained by the varied forest ownership structures (private vs. public), the need to perform specific tasks, and different political cultures and forest governance traditions (market-based vs. state-centered regulations). For instance, in Romania as in other former socialist countries, decision-making in local forest management is often hindered by regulatory hurdles. Forest policy as such, based on a top-down, hierarchically imposed and enforced set of compulsory rules (Bouriaud et al., 2013), leaves little room for local expert knowledge involvement in the decisions on adaptation measures and their practical implementation. Likewise, forest owners have little, if any, room for manoeuvre in the management. In contrast, the Netherlands has a liberal regulatory environment with much respect for landowners' rights, resulting in much freedom for forest owners and managers to make their own decisions as regards forest management (Hoogstra-Klein et al., 2017).

In regard to forest ownership, the nature of ownership is assumed to play a key role in determining the course of adaptation actions (Ontl et al., 2017). Ownership may determine how forests will be managed, protected or neglected. At least in principle public forests are managed for multiple goods and services, while private forests are often managed for financial or utility benefits of their owners (Siry et al., 2005). However, these relationships vary across countries and depend on several other socio-economic circumstances (Nichiforel et al., 2018). In Europe, particularly high proportions of privately owned forest are found in France and Portugal (75% and 97%, respectively; Forest Europe et al., 2015). These countries, however, differ regarding a number of important aspects. For instance, according to our survey, 19% of French respondents said they were not at all concerned about the impacts of climate change on forests and 13% indicated that climate change adaptation efforts in forest management are not a priority for them at this time. By contrast, in Portugal, only 1% of respondents were not concerned at all, whereas 44% responded that they were very or extremely concerned. Nevertheless, a lower proportion of forest owners and managers in Portugal (15%) stated that they adapted their management practices in response to climate change compared to those surveyed in France (52%). Although apparently contradictory, these results reflect the complexity of addressing forest adaptation in an integrated manner. If one looks at the constraints associated with adaptation, none of the other countries surveyed gets close to the 49% of Portuguese respondents who regard financial constraints as their foremost obstacle. The excessive fragmentation of property, which results in low profitability, the depopulation of rural areas, forest owners' absenteeism and population aging are other reasons that hinder the implementation of climate change adaptation measures (Pinto-Correia, 2000). At the national level, the absence of forest records and the lack of long-term forest planning further exacerbates the problem and increases the susceptibility of forests to climate risks. This is of particular concern given that catastrophic wildfires, as recently seen in central Portugal and southern Spain, are likely to increase in frequency, intensity and extent (Moreira et al., 2011). It is also worth noting that the current observed low adoption rate of climate change coping strategies in Portugal is contrary to that of Blennow et al. (2012) who, at the time of the study, noted that the largest fraction of respondents who stated they had taken measures to adapt were found in Portugal (54%), followed by those in Germany (47%) and Sweden (20%). Their study, however, was limited to a single forest owners' association and thus represent a sparse and, most likely, spatial and institutional biased sampling of the Portuguese context ($N = 69$). On the contrary, in this study, we have surveyed forest owners in the north, central and south regions of Portugal, which we believe better reflect a geographically more balanced perspective on the views on forest management and climate change adaptation in the country.

Finally, Slovakia stood out as having the greatest adaptation awareness (76%) and action (57%) of the seven countries surveyed. A possible explanation for this might be related to the severe storm damages suffered in 2004, when a 'catastrophic windstorm' and subsequent bark beetle outbreaks resulted in the destruction of an area of 12.600 ha with the volume of fallen wood estimated at 2.3 million - cubic meters (Jonášová et al., 2010). In fact, this is reflected in our results by the largest number of respondents (80%) who report having personally experienced climate-induced changes in forests. After the storm and widespread insect damage, the climate change issue became a matter of widespread public discussion in the country and engaged the interest of many for adaptation and mitigation strategies. Therefore, the need to prevent such large-scale disturbances (e.g., through management practices less vulnerable to storms) was presented as important to everyone. This was also reflected in changes in forestry policies and strategies. For instance, an online GIS platform was introduced in 2011 to support forestry practitioners with a free flow of information (Jankovič et al., 2011). It provides guidance and support to define the timing and location of forest management options based on permanently updated information about the state of forests and it is specified for use in state and private forests (Tuček et al., 2015). Also noteworthy is that, when asked about what they felt were the main constraints to implementing adaptation in forest management, lack of technological knowledge and information ranked the lowest in terms of importance with respect to other constraints. Taken together, these findings suggest that severe, locally damaging weather events, such as wind-throws, present significant opportunities to engage people with climate change, strengthen forest communication and encourage action (Spence et al., 2011). In addition, subsequent insect outbreaks, which often result in costly damages not only in the year of the occurrence but also in later years, may serve as a reminder of the impacts to be expected from climate change.

5. Conclusions

This study was set out to investigate, through survey data, how European forest owners and managers perceive climate change and are adapting their management to it. Forests can play an important role in tackling climate change and forest practitioners have a fundamental role in developing and implementing adaption measures into their forest management. In general, we found widespread belief in climate change (91% of respondents) but we also found that this high awareness of the changing climate change has not yet been translated into action. Our findings suggest that the level of adaptation in the forest sector differs widely across countries. For instance, in France, 50% of forest owners stated they had taken measures to adapt the management of their forest to climate change. In Slovakia, this figure increases to 57%, in contrast with Portugal where it does not exceed 15%. We also showed that lack of technical knowledge and information ranked high as a constraint in nearly every country, with the exception of Slovakia where it is ranked last.

Taken together, these results highlight the need for effective dissemination of information on the need to adapt forest management to climate change, and methodologies for achieving this. Ideally, as situations vary from one country to another, European level policy efforts would include a mixture of uniform collective actions and country-specific actions tailored to address the specific needs of specific

countries.

Finally, as numerous countries have already developed adaptation strategies and action plans that can be used as learning examples, especially where expected climate change impacts on forests (e.g., in central Europe) will mirror those currently experienced (e.g., in southern Europe), it is essential to facilitate knowledge sharing and training, and policies that encourage adaptation. Of equal importance, further work needs to be done to strengthen the relationship between scientific research and forest management to ensure an effective transfer of knowledge into practice. For instance, general interest in mixed forests has increased substantially in recent years but the scientific knowledge related to the management of mixtures is still scarce (Coll et al., 2018). Future research may also facilitate the translation of new knowledge into practical outcomes that are tailored and adapted to regional and local needs. More studies are also needed to evaluate perceptions over time and assess the effectiveness of adaptation actions in different governance-policy contexts.

Acknowledgments

The authors would like to thank the anonymous reviewers for their valuable comments and suggestions to improve the quality of the paper. They are also grateful to all the respondents, and the forest groups for helping us collecting responses from their members. In particular, we thank Kaie Kriiska, Mart Külvik and Robert Gerald Henry Bunce (Estonia); Geerten Hengeveld (The Netherlands); João C. Azevedo (IPB, Portugal); Joana Bateiro (Forestis, Portugal); and Liviu Nichiforel (Romania), who helped us to implement the survey in their respective countries. This research was funded by BELSPO, project FORBIO Climate (Belgium); by FCT-Portuguese Foundation for Science and Technology, project FARSYD-2011–2016–POCI-01-0145-FEDER-016664; and by Romanian Agency UEFISCDI, project PN-II-RU-TE-2011-3-0222. AL is supported by FCT through postdoctoral grant SFRH/BPD/80747/2011.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forpol.2018.01.004.

References

Allen, C.D., Macalady, A.K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D.D., Hogg, E.H. (Ted), Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J.-H., Allard, G., Running, S.W., Semerci, A., Cobb, N., 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For. Ecol. Manag. 259, 660–684. http://dx.doi.org/10.1016/j.foreco.2009.09.001.

André, K., Bruzell, S., Gerger Swartling, Å., Jönsson, A.M., Lagergren, F., Vulturius, G., Blennow, K., Carlsen, H., Engström, K., Hassler, J., Lindeskog, M., Olsson, O., 2015. Klimatanpassat skogsbruk : drivkrafter, risker och möjligheter : Mistra-SWECIA syntesrapport. Mistra-Swecia.

Bergh, J., Freeman, M., Sigurdsson, B., Kellomäki, S., Laitinen, K., Niinistö, S., Peltola, H., Linder, S., 2003. Modelling the short-term effects of climate change on the productivity of selected tree species in Nordic countries. For. Ecol. Manag. 183, 327–340. http://dx.doi.org/10.1016/S0378-1127(03)00117-8.

Bernier, P., Schoene, D., 2009. Adapting forests and their management to climate change: An overview. Unasylva 5–11.

Biesbroek, G.R., Swart, R.J., Carter, T.R., Cowan, C., Henrichs, T., Mela, H., Morecroft, M.D., Rey, D., 2010. Europe adapts to climate change: comparing national adaptation strategies. Glob. Environ. Chang. 20, 440–450. http://dx.doi.org/10.1016/j.gloenvcha.2010.03.005.

Blennow, K., Persson, J., 2009. Climate change: motivation for taking measure to adapt. Glob. Environ. Chang. 19, 100–104. http://dx.doi.org/10.1016/j.gloenvcha.2008.10.003.

Blennow, K., Persson, J., Tomé, M., Hanewinkel, M., 2012. Climate change: believing and seeing implies adapting. PLoS One 7, e50182. http://dx.doi.org/10.1371/journal.pone.0050182.

Bolte, A., Ammer, C., Löf, M., Madsen, P., Nabuurs, G.-J., Schall, P., Spathelf, P., Rock, J., 2009. Adaptive forest management in central Europe: climate change impacts, strategies and integrative concept. Scand. J. For. Res. 24, 473–482. http://dx.doi.org/10.1080/02827580903418224.

Bouriaud, L., Nichiforel, L., Weiss, G., Bajraktari, A., Curovic, M., Dobsinska, Z., Glavonjic, P., Jarský, V., Sarvasova, Z., Teder, M., Zalite, Z., 2013. Governance of private forests in Eastern and Central Europe: an analysis of forest harvesting and management rights. Ann. For. Res. 56, 199–215. http://dx.doi.org/10.15287/AFR.2013.54.

Bouriaud, L., Marzano, M., Lexer, M., Nichiforel, L., Reyer, C., Temperli, C., Peltola, H., Elkin, C., Duduman, G., Taylor, P., Bathgate, S., Borges, J.G., Clerkx, S., Garcia-Gonzalo, J., Gracia, C., Hengeveld, G., Kellomäki, S., Kostov, G., Maroschek, M., Muys, B., Nabuurs, G.J., Nicoll, B., Palahí, M., Rammer, W., Ray, D., Schelhaas, M.J., Sing, L., Tomé, M., Zell, J., Hanewinkel, M., 2015. Institutional factors and opportunities for adapting European forest management to climate change. Reg. Environ. Chang. 15, 1595–1609. http://dx.doi.org/10.1007/s10113-015-0852-8.

Ciancio, O., Nocentini, S., 2011. Biodiversity conservation and systemic silviculture: concepts and applications. Plant Biosyst. 145, 411–418. http://dx.doi.org/10.1080/11263504.2011.558705.

Coll, L., Ameztegui, A., Collet, C., Löf, M., Mason, B., Pach, M., Verheyen, K., Abrudan, I., Barbati, A., Barreiro, S., Bielak, K., Bravo-Oviedo, A., Ferrari, B., Govedar, Z., Kulhavy, J., Lazdina, D., Metslaid, M., Mohren, F., Pereira, M., Peric, S., Rasztovits, E., Short, I., Spathelf, P., Sterba, H., Stojanovic, D., Valsta, L., Zlatanov, T., Ponette, Q., 2018. Knowledge gaps about mixed forests: what do European forest managers want to know and what answers can science provide? For. Ecol. Manag. 407, 106–115. http://dx.doi.org/10.1016/j.foreco.2017.10.055.

Crowther, T.W., Glick, H.B., Covey, K.R., Bettigole, C., Maynard, D.S., Thomas, S.M., Smith, J.R., Hintler, G., Duguid, M.C., Amatulli, G., Tuanmu, M.-N., Jetz, W., Salas, C., Stam, C., Piotto, D., Tavani, R., Green, S., Bruce, G., Williams, S.J., Wiser, S.K., Huber, M.O., Hengeveld, G.M., Nabuurs, G.-J., Tikhonova, E., Borchardt, P., Li, C.-F., Powrie, L.W., Fischer, M., Hemp, A., Homeier, J., Cho, P., Vibrans, A.C., Umunay, P.M., Piao, S.L., Rowe, C.W., Ashton, M.S., Crane, P.R., Bradford, M.A., 2015. Mapping tree density at a global scale. Nature 525, 201–205. http://dx.doi.org/10.1038/nature14967.

Dale, V., Joyce, L., McNulty, S., Neilson, R., 2001. Climate change and forest disturbances: climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species. Bioscience 51 (9), 723–734. http://dx.doi.org/10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2. (2001, September 1).

de Bruin, J.O., Hoogstra-Klein, M.A., Mohren, G.M.J., Arts, B.J.M., 2015. Complexity of forest management: exploring perceptions of Dutch forest managers. Forests 6, 3237–3255. http://dx.doi.org/10.3390/f6093237.

Demski, C., Capstick, S., Pidgeon, N., Sposato, R.G., Spence, A., 2016. Experience of extreme weather affects climate change mitigation and adaptation responses. Clim. Chang. 140, 1–16. http://dx.doi.org/10.1007/s10584-016-1837-4.

EEA, 2017. Climate Change, Impacts and Vulnerability in Europe 2016: An Indicator-Based Report. Publications Office of the European Union, Luxembourg. http://dx.doi.org/10.2800/534806.

Fady, B., Cottrell, J., Ackzell, L., Alía, R., Muys, B., Prada, A., González-Martínez, S.C., 2016. Forests and global change: what can genetics contribute to the major forest management and policy challenges of the twenty-first century? Reg. Environ. Chang. 16, 927–939. http://dx.doi.org/10.1007/s10113-015-0843-9.

FAO, 2012. Forest management and climate change: stakeholder perceptions. In: Forests and Climate Change Working Paper 11. Food and Agriculture Organization of the United Nations, Rome, Italy.

Fernandez-Gimenez, M.E., Ballard, H.L., Sturtevant, V.E., 2008. Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. Ecol. Soc. 13, 4. http://dx.doi.org/10.5751/ES-02400-130204.

Forest Europe, UNECE, FAO, 2015. State of Europe's Forests 2015. Status and Trends in Sustainable Forest Management in Europe. Ministerial Ministerial Conference on the Protection of Forests in Europe, Forest Europe, Liaison Unit Madrid, Madrid.

Gamborg, C., Larsen, J.B., 2003. "Back to nature" - a sustainable future for forestry? For. Ecol. Manag. 179, 559–571. http://dx.doi.org/10.1016/S0378-1127(02)00553-4.

Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob. Environ. Chang. 15, 199–213. http://dx.doi.org/10.1016/j.gloenvcha.2005.01.002.

Heltorp, K.M.A., Kangas, A., Hoen, H.F., 2017. Do forest decision-makers in southeastern Norway adapt forest management to climate change? Scand. J. For. Res. 1–13. http://dx.doi.org/10.1080/02827581.2017.1362463.

Hoogstra-Klein, M.A., Brukas, V., Wallin, I., 2017. Multiple-use forestry as a boundary object: from a shared ideal to multiple realities. Land Use Policy 69, 247–258. http://dx.doi.org/10.1016/j.landusepol.2017.08.029.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team, R.K. Pachauri L.A. Meyer ed. (Geneva, Switzerland).

Jankovič, J., Cibuľa, R., Pôbiš, I., Kajba, M., 2011. Forestry GIS: new generation information system on forests. In: Tuček, J., Suchomel, J., Gejdoš, M., Jurica, J. (Eds.), Progressive Methods for Processing of Incidental Fellings. Proceedings of International Scientific Conference Technical University in Zvolen, pp. 79–85.

Jonášová, M., Vávrová, E., Cudlín, P., 2010. Western Carpathian mountain spruce forest after a windthrow: natural regeneration in cleared and uncleared areas. For. Ecol. Manag. 259, 1127–1134. http://dx.doi.org/10.1016/j.foreco.2009.12.027.

Joyce, L.A., Blate, G.M., McNulty, S.G., Millar, C.I., Moser, S., Neilson, R.P., Peterson, D.L., 2009. Managing for multiple resources under climate change: national forests. Environ. Manag. 44, 1022–1032. http://dx.doi.org/10.1007/s00267-009-9324-6.

Jump, A.S., Hunt, J.M., Peñuelas, J., 2006. Rapid climate change-related growth decline at the southern range edge of Fagus sylvatica. Glob. Chang. Biol. 12, 2163–2174. http://dx.doi.org/10.1111/j.1365-2486.2006.01250.x.

Keenan, R.J., 2015. Climate change impacts and adaptation in forest management: a review. Ann. For. Sci. 72, 145–167. http://dx.doi.org/10.1007/s13595-014-0446-5.

Kempeneers, P., Sedano, F., Seebach, L., Strobl, P., San-Miguel-Ayanz, J., 2011. Data fusion of different spatial resolution remote sensing images applied to forest-type mapping. IEEE Trans. Geosci. Remote Sens. 49, 4977–4986.
Keskitalo, E.C.H., 2011. How can Forest management adapt to climate change? Possibilities in different forestry systems. Forests 2, 415–430. http://dx.doi.org/10.3390/f2010415.
Keskitalo, E.C.H., Legay, M., Marchetti, M., Nocentini, S., Spathelf, P., 2015. The role of forestry in national climate change adaptation policy: cases from Sweden, Germany, France and Italy. Int. For. Rev. 17, 30–42. http://dx.doi.org/10.1505/146554815814725068.
Kolström, M., Lindner, M., Vilén, T., Maroschek, M., Seidl, R., Lexer, M.J., Netherer, S., Kremer, A., Delzon, S., Barbati, A., Marchetti, M., Corona, P., 2011. Reviewing the science and implementation of climate change adaptation measures in European forestry. Forests 2, 961–982. http://dx.doi.org/10.3390/f2040961.
Kurz, W.A., Dymond, C.C., Stinson, G., Rampley, G.J., Neilson, E.T., Carroll, A.L., Ebata, T., Safranyik, L., 2008. Mountain pine beetle and forest carbon feedback to climate change. Nature 452, 987–990. http://dx.doi.org/10.1038/nature06777.
Lawrence, A., Marzano, M., 2013. Is the private forest sector adapting to climate change? A study of forest managers in north Wales. Ann. For. Sci. 71, 291–300. http://dx.doi.org/10.1007/s13595-013-0326-4.
Lindner, M., Garcia-Gonzalo, J., Kolström, M., Green, T., Reguera, R., Maroschek, M., Seidl, R., Lexer, M.J., Netherer, S., Schopf, A., Kremer, A., Delzon, S., Barbati, A., Marchetti, M., Corona, P., 2008. Impacts of Climate Change on European Forests and Options for Adaptation, Report to the European Commission Directorate-General for Agriculture and Rural Development. (Brussels, Belgium). http://ec.europa.eu/agriculture/analysis/external/euro_forests/.
Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M.J., Marchetti, M., 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For. Ecol. Manag. 259, 698–709. http://dx.doi.org/10.1016/j.foreco.2009.09.023.
Lindner, M., Fitzgerald, J.B., Zimmermann, N.E., Reyer, C., Delzon, S., van der Maaten, E., Schelhaas, M.-J.J., Lasch, P., Eggers, J., van der Maaten-Theunissen, M., Suckow, F., Psomas, A., Poulter, B., Hanewinkel, M., 2014. Climate change and European forests: what do we know, what are the uncertainties, and what are the implications for forest management? J. Environ. Manag. http://dx.doi.org/10.1016/j.jenvman.2014.07.030.
Maibach, E., Myers, T., Leiserowitz, A., 2014. Climate scientists need to set the record straight: there is a scientific consensus that human-caused climate change is happening. Earth's Futur. 2, 295–298. http://dx.doi.org/10.1002/2013EF000226.
MEDDE, 2011. Plan national d'adaptation de la France aux effets du changement climatique, 2011–2015.
Messier, C., Puettmann, K., Chazdon, R., Andersson, K.P., Angers, V.A., Brotons, L., Filotas, E., Tittler, R., Parrott, L., Levin, S.A., 2015. From management to stewardship: viewing forests as complex adaptive Systems in an Uncertain World. Conserv. Lett. 8, 368–377. http://dx.doi.org/10.1111/conl.12156.
Messier, C., Puettmann, K., Filotas, E., Coates, D., 2016. Dealing with non-linearity and uncertainty in forest management. Curr. For. Reports 2, 150–161. http://dx.doi.org/10.1007/s40725-016-0036-x.
Millar, C.I., Stephenson, N.L., Stephens, S.L., 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecol. Appl. 17, 2145–2151. http://dx.doi.org/10.1890/06-1715.1.
Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Barbati, A., Corona, P., Vaz, P., Xanthopoulos, G., Mouillot, F., Bilgili, E., 2011. Landscape - wildfire interactions in southern Europe: implications for landscape management. J. Environ. Manag. http://dx.doi.org/10.1016/j.jenvman.2011.06.028.
Nelson, H.W., Williamson, T.B., Macaulay, C., Mahony, C., 2016. Assessing the potential for forest management practitioner participation in climate change adaptation. For. Ecol. Manag. 360, 388–399. http://dx.doi.org/10.1016/j.foreco.2015.09.038.
Nichiforel, L., Keary, K., Deuffic, P., Weiss, G., Thorsen, B., Winkel, G., Avdibegovic, M., Dobsinska, Z., Feliciano, D., Gatto, P., Gorriz-Mifsud, E., Hoogstra, M., Hrib, M., Hujala, T., Jager, L., Jarský, V., Jodlowski, K., Lawrence, A., Lukmine, D., Pezdevsek Malovrh, S., Nedeljkovic, J., Nonić, D., Krajter Ostoić, S., Pukall, K., Rondeux, J., Samara, T., Stojanovska, M., Stojanovski, V., Stoyanov, N., Wilhelmsson, E., Wilkes-Allemann, J., Teder, M., Scriban, R.E., Sarvasova, Z., Silingiene, R., Sinko, M., Vilkriste, L., Vennesland, B., Bouriaud, L., 2018. How Private Are Europe's Private Forests? A Comparative Property Rights Analysis. (Land use policy).
Nocentini, S., Buttoud, G., Ciancio, O., Corona, P., 2017. Managing forests in a changing world: the need for a systemic approach. A review. For. Syst. http://dx.doi.org/10.5424/fs/2017261-09443.
O'Hara, K.L., 2016. What is close-to-nature silviculture in a changing world? Forestry 89, 1–6. http://dx.doi.org/10.1093/forestry/cpv043.
Ontl, T.A., Swanston, C., Brandt, L.A., Butler, P.R., D'Amato, A.W., Handler, S.D., Janowiak, M.K., Shannon, P.D., 2017. Adaptation pathways: ecoregion and land ownership influences on climate adaptation decision-making in forest management. Clim. Chang. 1–14. http://dx.doi.org/10.1007/s10584-017-1983-3.
Petr, M., Boerboom, L., Ray, D., van der Veen, A., 2014. An uncertainty assessment framework for forest planning adaptation to climate change. For. Policy Econ. 41, 1–11. http://dx.doi.org/10.1016/j.forpol.2013.12.002.
Pickens, J., 2005. Attitudes and perceptions. In: Organizational Behavior in Health Care. Jones and Bartlett Publishers, Sudbury, pp. 43–75.
Pinto-Correia, T., 2000. Future development in Portuguese rural areas: how to manage agricultural support for landscape conservation? Landsc. Urban Plan. 50, 95–106. http://dx.doi.org/10.1016/S0169-2046(00)00082-7.
Reser, J.P., Bradley, G.L., Ellul, M.C., 2014. Encountering climate change: “seeing” is more than “believing”. Wiley Interdiscip. Rev. Clim. Chang. 5, 521–537. http://dx.doi.org/10.1002/wcc.286.
Schoene, D.H.F., Bernier, P.Y., 2012. Adapting forestry and forests to climate change: a challenge to change the paradigm. For. Policy Econ. 24, 12–19. http://dx.doi.org/10.1016/j.forpol.2011.04.007.
Seidl, R., Schelhaas, M.-J., Rammer, W., Verkerk, P.J., 2014. Increasing forest disturbances in Europe and their impact on carbon storage. Nat. Clim. Chang. 4, 806–810. http://dx.doi.org/10.1038/nclimate2318.
Seppälä, R., 2009. Adaptation of forests and people to climate change. In: Adaptation of Forests and People to Climate Change - A Global Assessment Report.
Siry, J.P., Cubbage, F.W., Ahmed, M.R., 2005. Sustainable forest management: global trends and opportunities. For. Policy Econ. http://dx.doi.org/10.1016/j.forpol.2003.09.003.
Sousa-Silva, R., Ponette, Q., Verheyen, K., Van Herzele, A., Muys, B., 2016. Adaptation of forest management to climate change as perceived by forest owners and managers in Belgium. For. Ecosyst. 3, 22. http://dx.doi.org/10.1186/s40663-016-0082-7.
Spathelf, P., van der Maaten, E., van der Maaten-Theunissen, M., Campioli, M., Dobrowolska, D., 2014. Climate change impacts in European forests: the expert views of local observers. Ann. For. Sci. 71, 131–137. http://dx.doi.org/10.1007/s13595-013-0280-1.
Spence, A., Poortinga, W., Butler, C., Pidgeon, N.F., 2011. Perceptions of climate change and willingness to save energy related to flood experience. Nat. Clim. Chang. 1, 46–49. http://dx.doi.org/10.1038/nclimate1059.
Tuček, J., Sedmák, R., Majlingová, A., Sedliak, M., Marques, S., 2015. Decision support systems in Slovak forestry planning: a review Systémy na podporu rozhodovania v lesníckom plánovaní na Slovensku. Preh'ad For. J. 61, 19–30. http://dx.doi.org/10.1515/forj-2015-0010.
Wagner, S., Nocentini, S., Huth, F., Hoogstra-Klein, M., 2014. Forest management approaches for coping with the uncertainty of climate change: trade-offs in service provisioning and adaptability. Ecol. Soc. 19 art32. https://doi.org/10.5751/ES-06213-190132.
Yousefpour, R., Hanewinkel, M., 2015. Forestry professionals' perceptions of climate change, impacts and adaptation strategies for forests in south-west Germany. Clim. Chang. 130, 273–286. http://dx.doi.org/10.1007/s10584-015-1330-5.